Droplet-Routing-Aware Module Placement for Cross-Referencing Biochips

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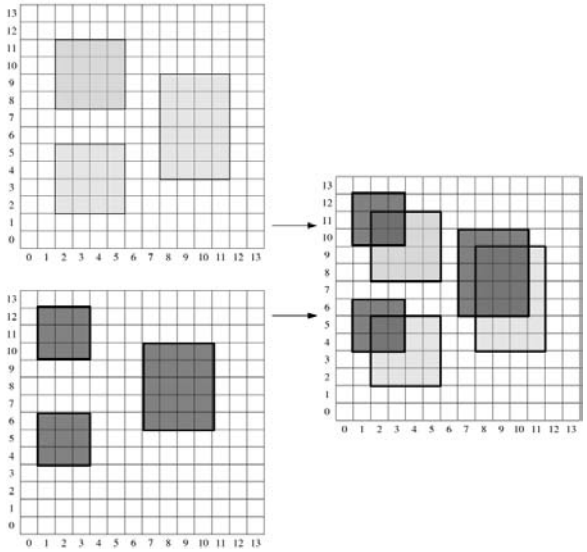
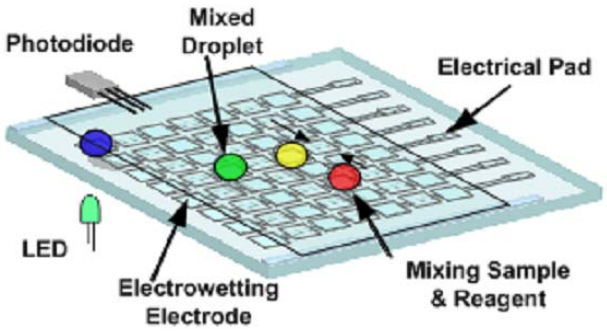
Outline

1. Background: Biochip & CAD
2. Problem Formulation & ILP Modeling
3. Experimental Result
4. Conclusion



Background – DMFB and CAD

- *Digital Microfluidic Biochip* (DMFB)
- *Droplet* – Carrier of biochemical reaction material

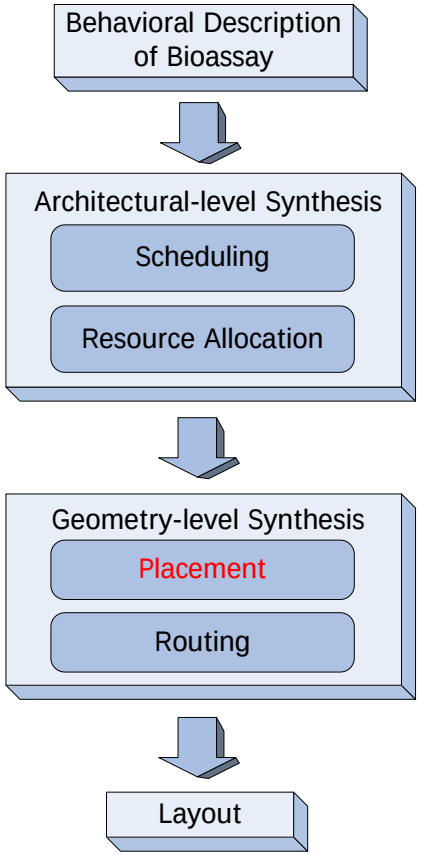


On-chip resources:

- Dispenser
- Waste reservoir
- Optical detector

Basic operations:

- Mixing
- Dilution
- Optical detection
- Storage



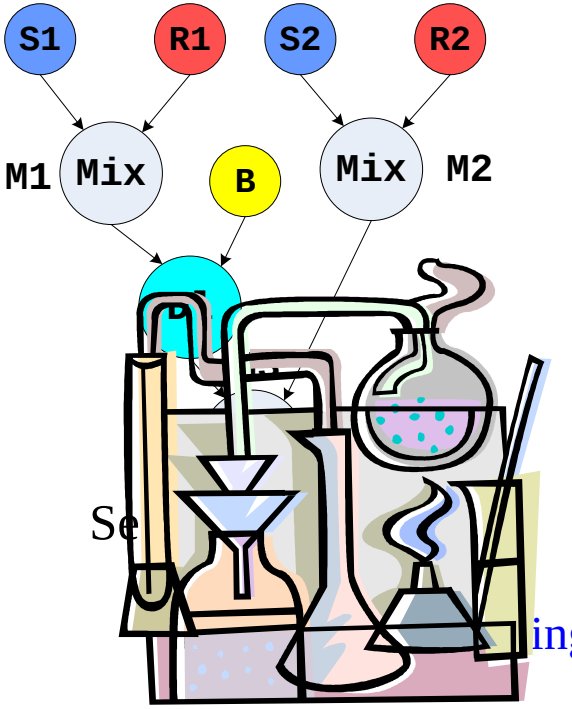
Top-down design flow [Su ICCAD'04]

Placement Problem - Illustration

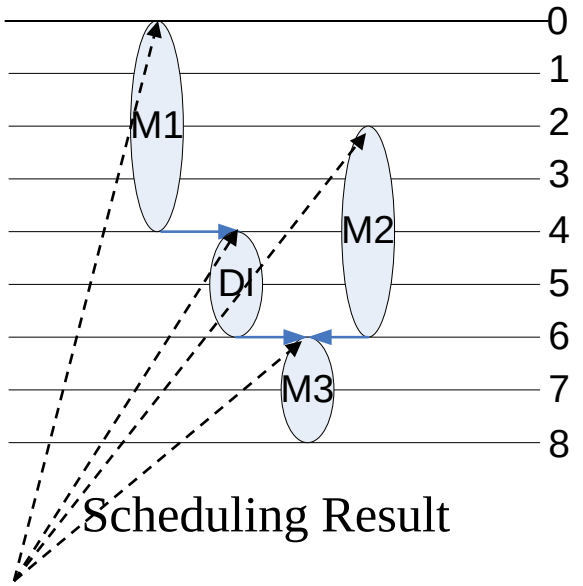
Chip Spec:

Size
Dispensers
TIME Constraint
...

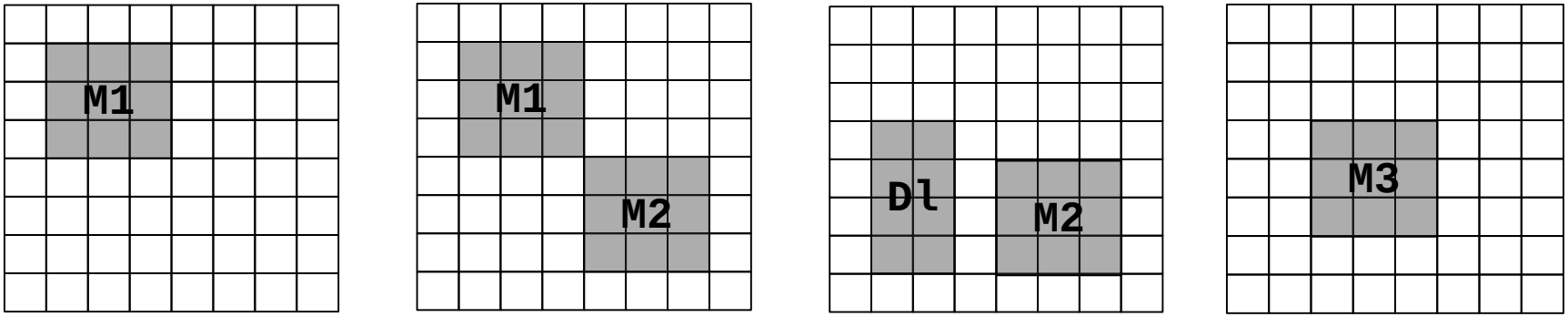
Chip Specification,
Assay Description



Se ing happens here



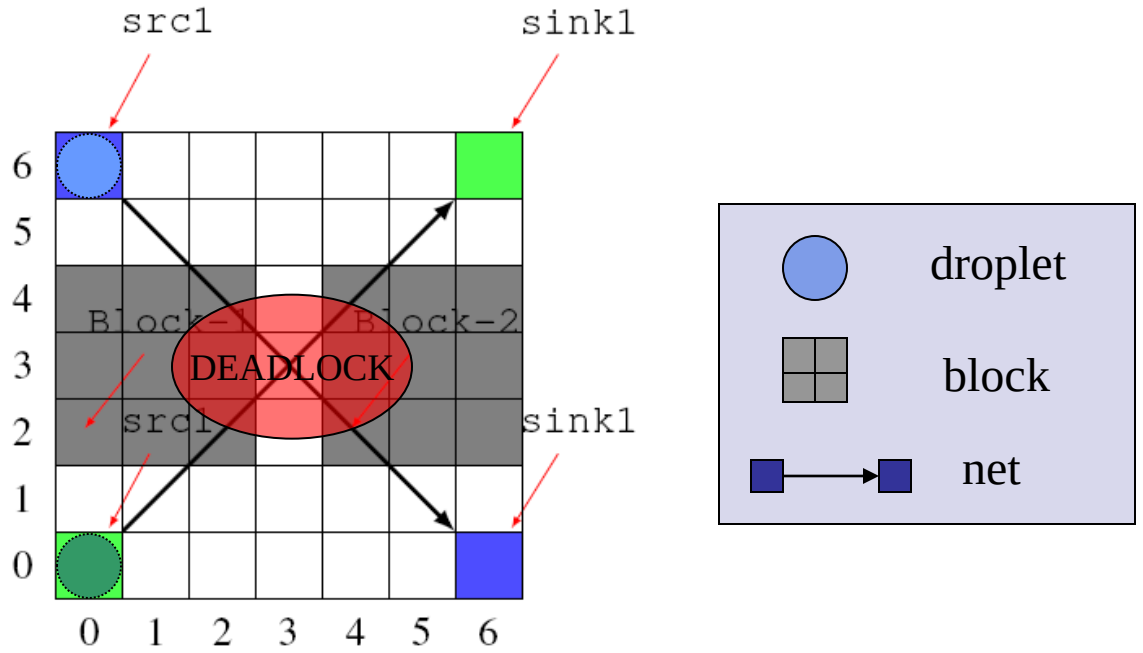
Scheduling Result



Time 0-2 **Time 2-4** **Time 4-6** **Time 6-8**

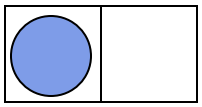
After Placement: Routing On Biochip

- Placement will greatly affects the routing:

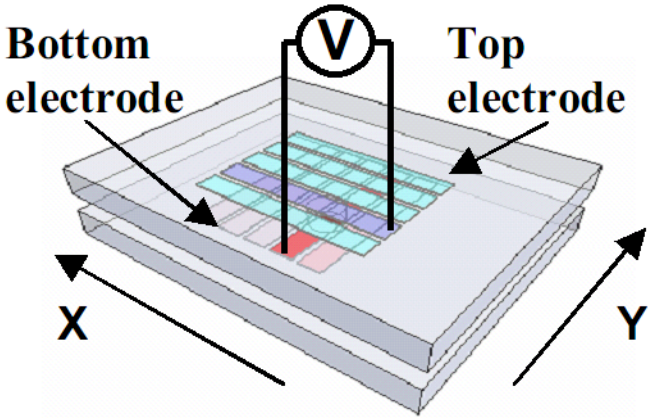


- Not a good placement result
- Should coordinate during routing – downgrade to sequential
  Also in the biochip routing….
- The chip type also affects the routing!

Cross-Referencing Biochip

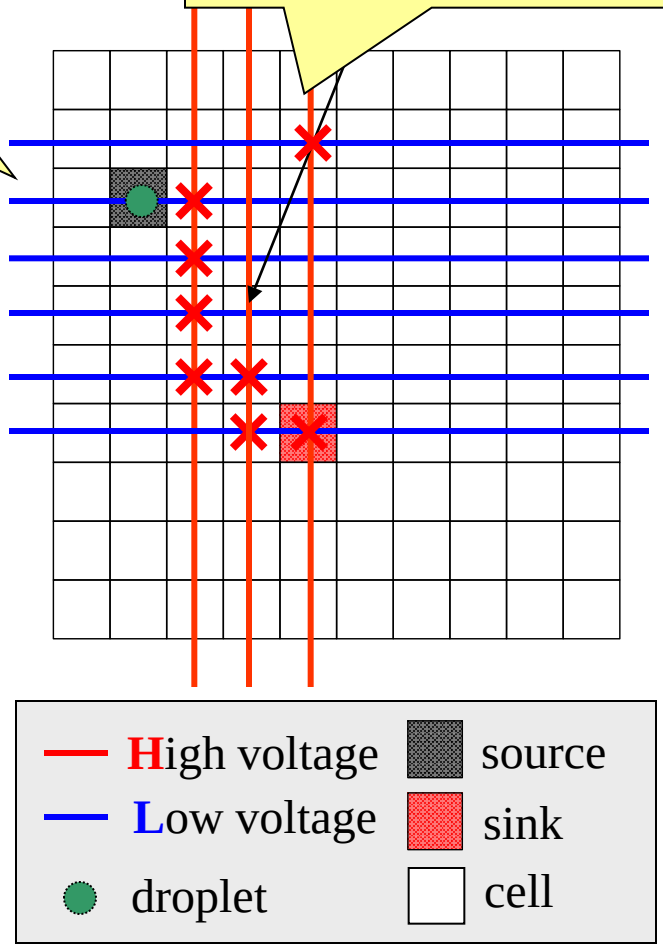


In Cross-Referencing we apply a ***sequence*** of ***Voltage Assignment***



(Cite from [Yuh DAC'08])

Apply a group of voltages to activate cells **simultaneously**



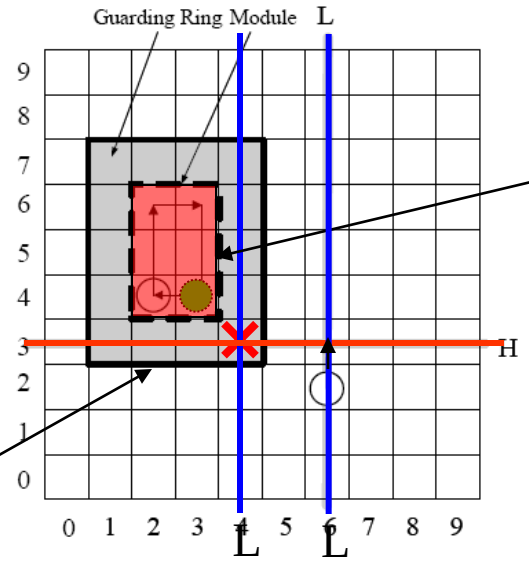
Special and hard problem:

- Routing several droplets simultaneously - *Electrode Interference*

Cross-Referencing Biochip - Block

- Issue of block (confirmed from DukeU)

If applied…



We assume extra-activated cell inside is fine. Still mixing inside

Cannot apply L to column 1~4

- Should be handled during routing.

Previous Work

- [Su DAC'05], [Su DATE'05], [Xu DAC'07], proposed methods based on *Simulated Annealing* (SA), using different representations. Fault-tolerance issue is also considered in their works.

- [Yuh JETC'07] proposed *T-tree based representations* to be used in SA.

- Note that none of them aimed on designing for *Cross-referencing* DMFB.

- **[Su DAC'05]** F. Su and K. Chakrabarty, "Unified high-level synthesis and module placement for defect-tolerant microfluidic biochips," in Proc. Design Automation Conference. ACM New York, NY, USA, 2005, pp. 825–830.
- **[Su DATE'05]** F. Su and K. Chakrabarty, "Design of fault-tolerant and dynamically-reconfigurable microfluidic biochips," in Proc. Design, Automation and Test in Europe, 2005, pp. 1202–1207.
- **[Xu DAC'07]** T. Xu and K. Chakrabarty, "Integrated droplet routing in the synthesis of microfluidic biochips," in Proc. Design Automation Conference. ACM Press New York, NY, USA, 2007, pp. 948–953.
- **[Yuh JETC'07]** P. Yuh, C. Yang, and Y. Chang, "Placement of defect-tolerant digital microfluidic biochips using the t-tree formulation," ACM Journal on Emerging Technologies in Computing Systems (JETC), vol. 3, no. 3, p. 13, 2007.

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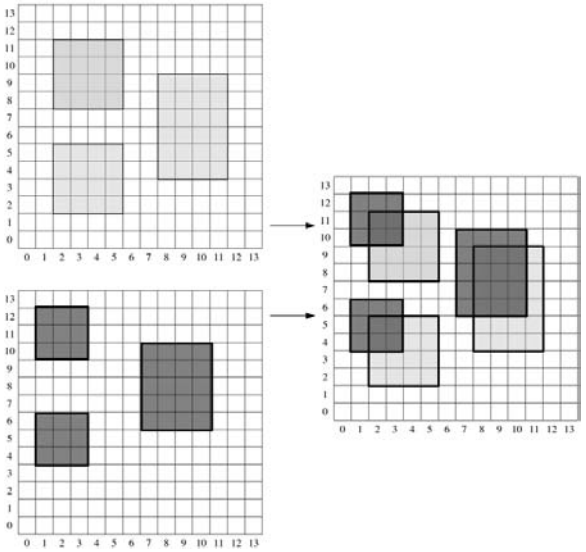
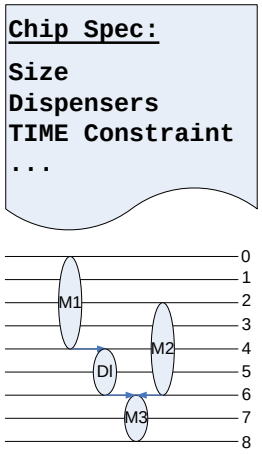


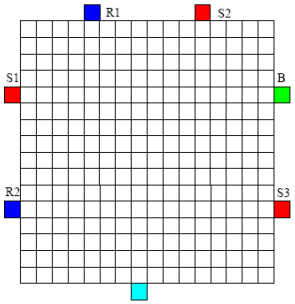
Problem Formulation

- *Input:*
  - Scheduling and resource binding result
  - Chip specification:
    - *Timing constraint T*
    - *Chip size WxH*
    - *Optical Detectors*
    - *Reservoir, dispenser*

- *Output:*
  - Placement result, including:
    - *Location of modules, reservoir and dispenser*
    - *Nets*

Overview of Our Approach



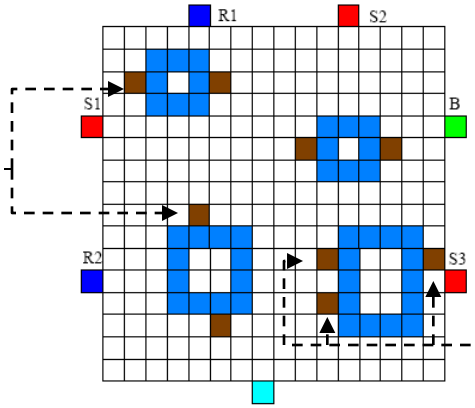


Decide dispenser and reservoir location

$$
\begin{aligned}
M_x^i - M_x^j - X(M^j) + L(c_1 + c_2) &> 1 \\
M_x^j - M_x^i - X(M^i) + L(c_1 + 1 - c_2) &> 1 \\
M_y^i - M_y^j - Y(M^j) + L(1 - c_1 + c_2) &> 1 \\
M_y^j - M_y^i - Y(M^i) + L(2 - c_1 - c_2) &> 1
\end{aligned}
$$

ILP formulation

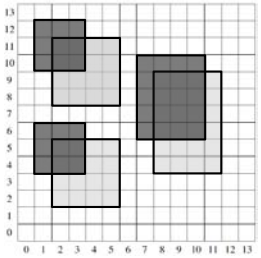
LP solver



Pins

Pins

Pin Generation



Output

Routing & Evaluation

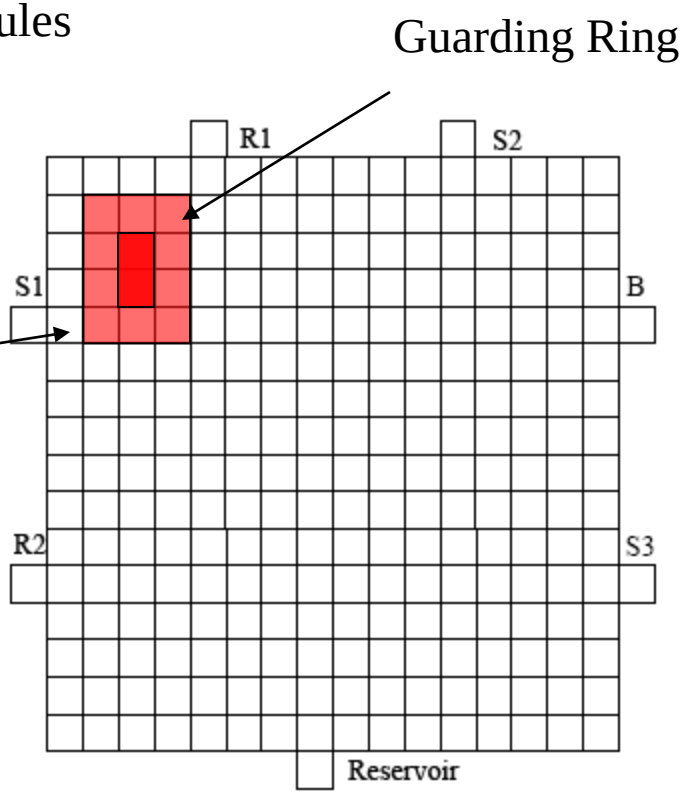
ILP Formulation of Placement

1. Validity constraint
2. Non-overlapping and separation constraint
3. Optical detector constraint
4. Reservoir constraint

- Core idea: how to utilize the properties of Cross-Referencing DMFB?
- Objective function:
  - Sum of *extended covered area*

Constraints - 1

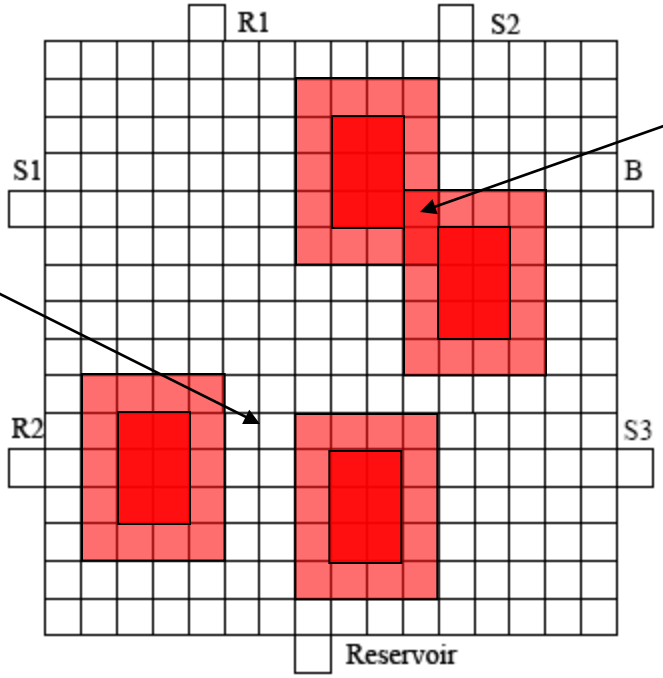
1. Validity of modules



Should be inside chip, one space away from boundary (otherwise block reservoir!)

Constraints - 2

2. Non-overlapping and separation

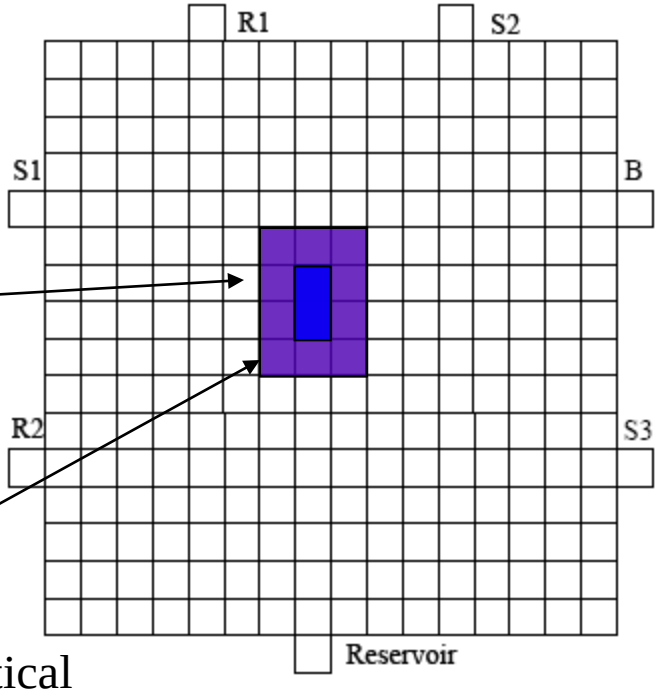


Guarding ring can be SHARED

Modules cannot overlap if co-exist at some time

Constraints - 3

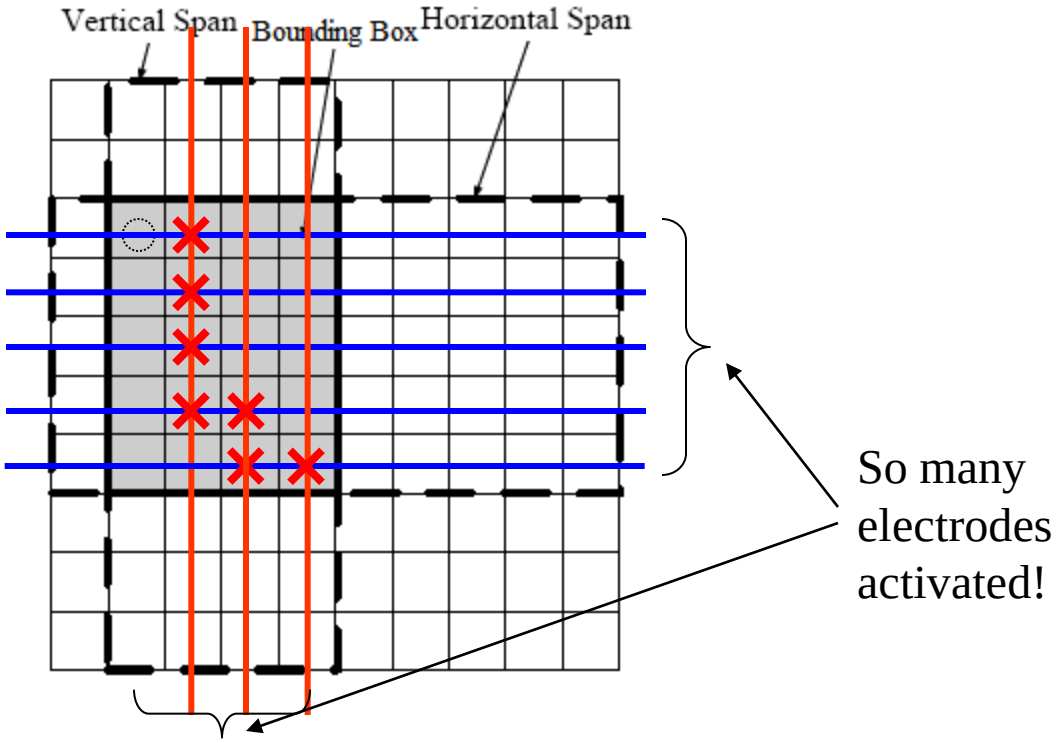
3. Optical detector resource constraint



Dt1, Dt2 bound to the same optical detector, should be at the same place!

Time=8~9

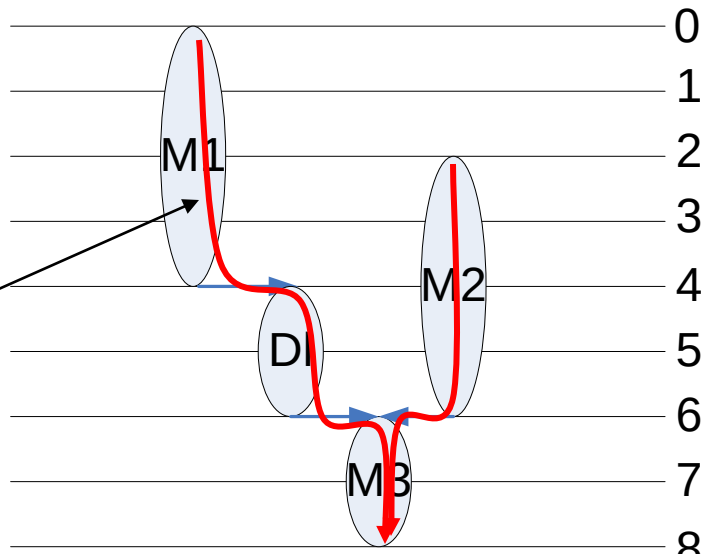
ILP - Extended Covered Area (ECA)



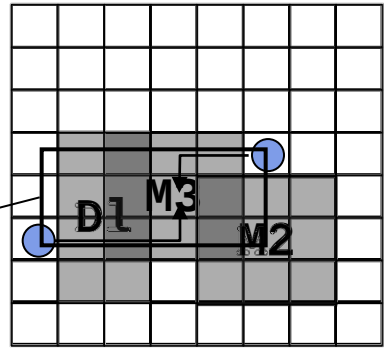
Minimize the sum of ECAs: rationale 1 – handles interference issue

- For multiple droplets : reduce the possibilities of interference between routes

ILP - Extended Covered Area (ECA) - cont.



Tries to minimize the overall moves in the whole assay



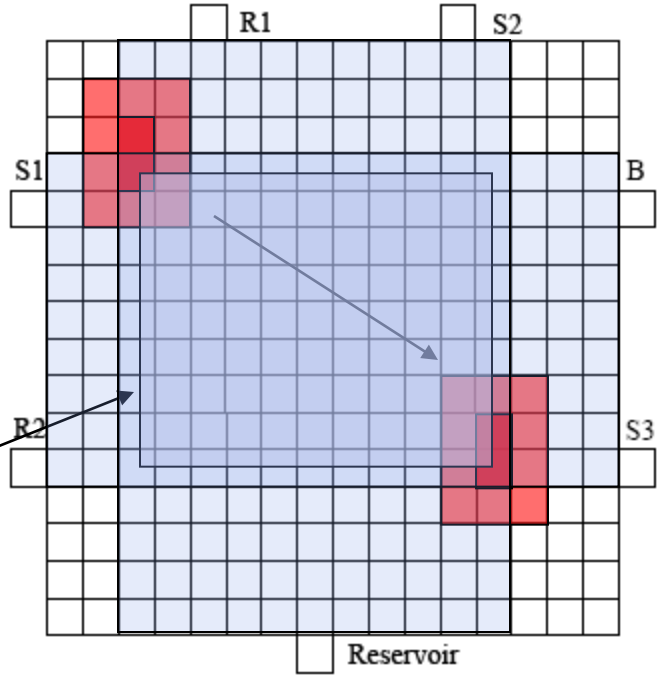
Rationale 2:

For a single droplet, also minimizes the Manhattan distance of route

Time 4-8

Objective

4. Bounding box of routes and objective

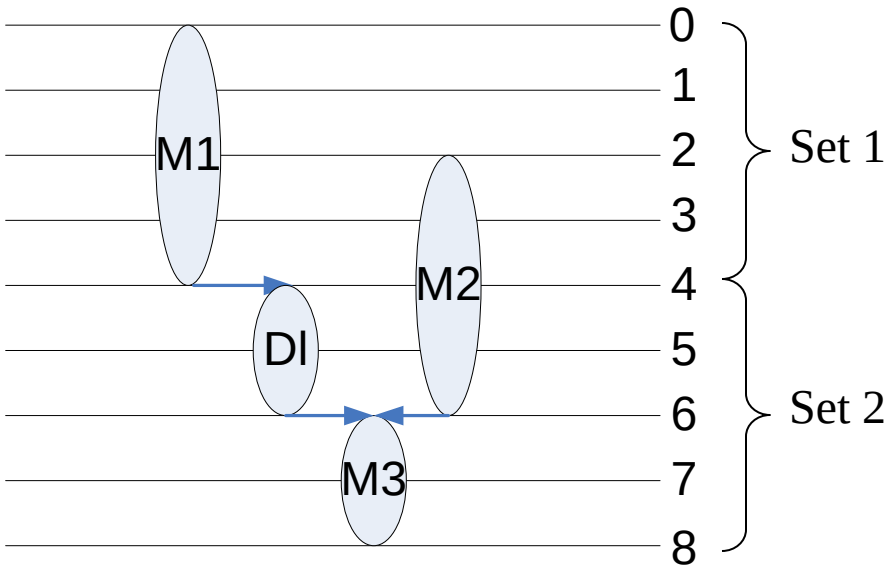


Objective = sum of all these ECAs

Subproblem i+1

Partition of Problems

- Some benchmarks contain numerous subproblems
- If solve as one ILP
  - # variables: 2069
  - # constraints: 4154
- Split it into several sets
- Output of subproblem i serves as input of subproblem i+1



Example: splitting into two sets

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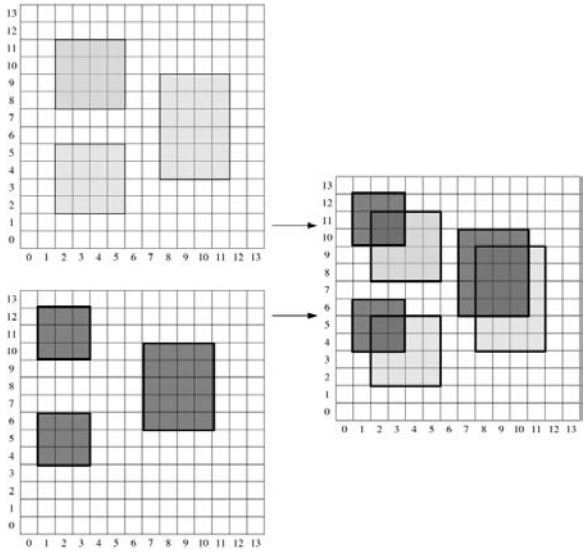
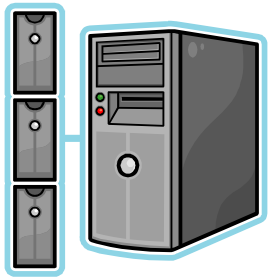


Experiment Setup

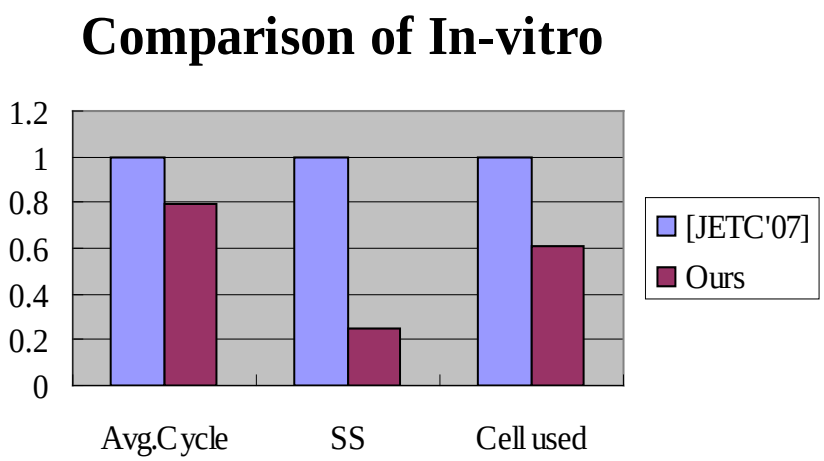
- Environment:
  - lp_solve 5.5
  - Intel 2.4GHz CPU
  - 1.5G Ram

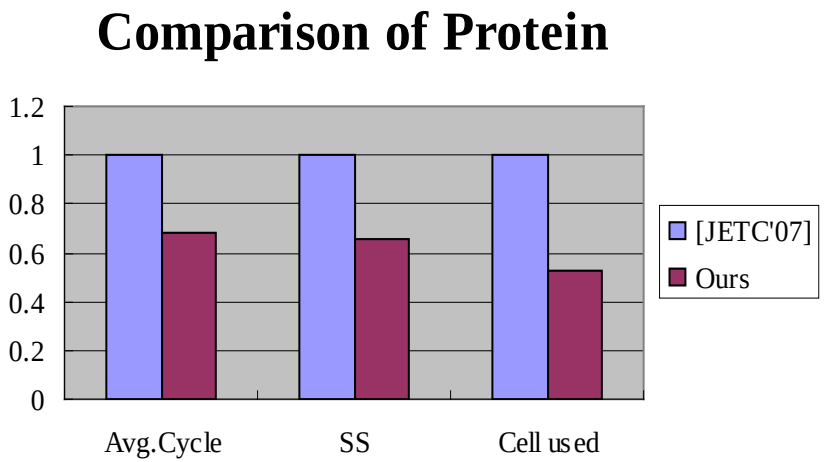


- Four sets of real world benchmarks
  - *In-vitro*
  - *In-vitro2*
  - *Protein*
  - *Protein2*

- A droplet router for cross-referencing biochip is adapted and used to evaluate the placement result [Xiao ASPDAC'10].

Experimental Result – Comparison





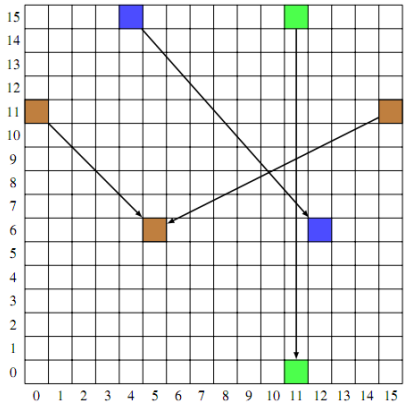
Benchmark	# sub*	Size	Routing on [Yuh JETC'07]			Routing on our placement		
			Max/Avg. cycle	SS°	Cell used	Max/Avg. cycle	SS.	Cell used
In-vitro	11	16x16	20/12.09	12	246	16/9.64	3	151
In-vitro2	15	14x14	19/10.73	23	250	17/6.40	5	104
Protein	64	21x21	20/15.52	38	1652	20/10.57	25	875
Protein2	78	13x13	20/9.87	40	974	20/10.88	75	952

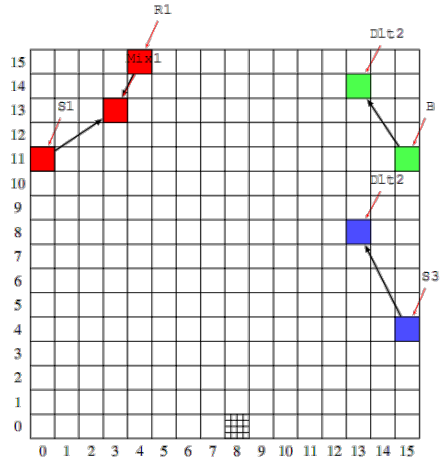
* #sub: number of subproblems in a benchmark.

o SS=Stalling Steps. Total number of stalling during routing.

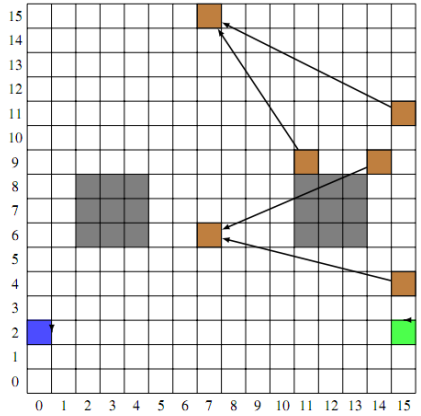
Sample Placement Result (*In-Vitro1*)

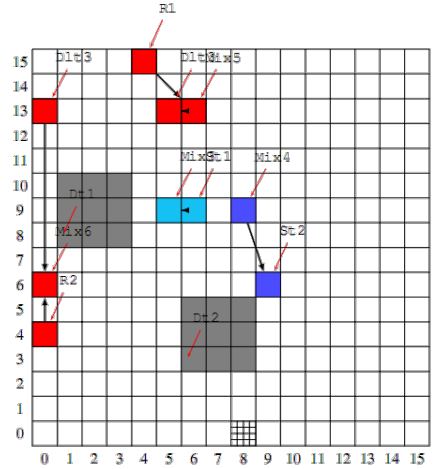
Subproblem 1:





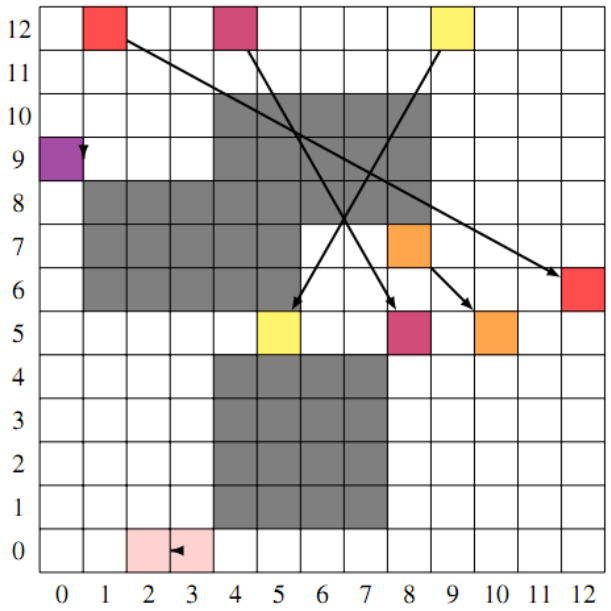
Subproblem 5:

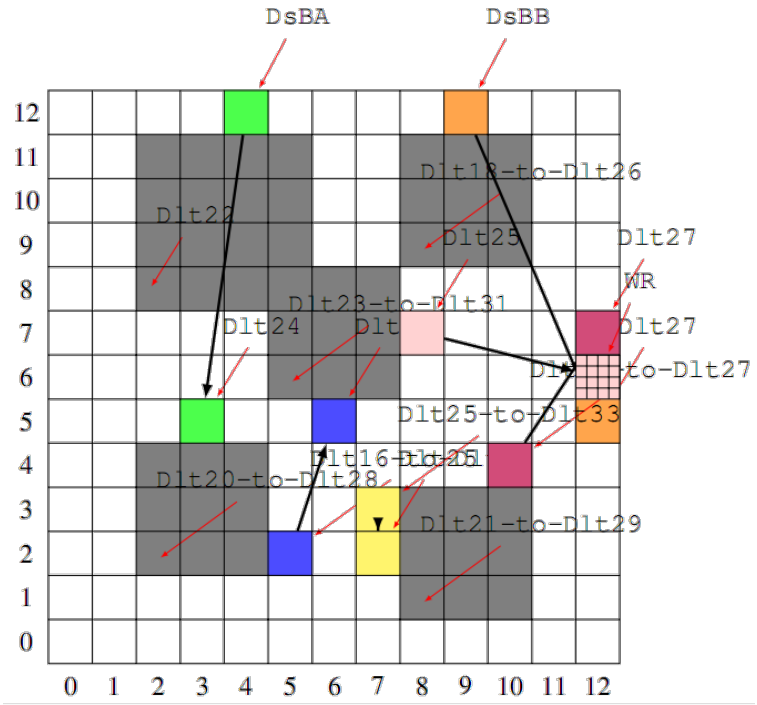




Harder Case

- From *Protein2*, small chip size with many on-going modules and nets.





Subproblem 37: five modules, six nets

Conclusion

- An ILP-based routing-aware placement method is presented and evaluated.
- The properties of cross-referencing is beneficial to routing. The objective function is simple but effective, and should be explored MORE.
- To better compare the solution quality, harder bioassay/protocol is needed to perform the placement and routing (both results are 100% routable for the router)

-Thank You -